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INFORMAL REPORT

# RADIOLOGICAL IMPACTS OF TRANSPORTING THREE MILE ISLAND CORE DEBRIS

Neil D. Cox



EG&G Idaho

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## ABSTRACT

Beginning in 1986, material from the damaged core of the Unit 2 reactor at the Three Mile Island Nuclear Power Station in Pennsylvania will be transported by rail to the Idaho National Engineering Laboratory for research. This report presents an assessment of the radiological impacts of transporting that core debris.

Using published unit consequence factors, for which it is assumed that the largest allowable radiation dose rate under statutes exists, the greatest exposure to the public because of a passing spent fuel cask was found to be 0.002 mrem for an individual 33 ft from the railroad track. In order to match the public exposure guideline adopted by the Federal Radiation Council and the Environmental Protection Agency, that individual would have to be present as 28 casks passed every hour for a year. Individuals also could receive doses by loitering near a spent fuel cask during train rest stops or while a train is stalled by an accident. In order to match the naturally occurring annual radiation dose, such an individual would have to loiter for 40% of a year.

It is also shown that an individual is 85% more likely to be evacuated because of a hazardous materials accident than because of a train carrying a spent fuel cask being stalled by an accident on mainline track. Based on cask tests and accident experience, the possibility of a cask being breached in an accident is remote. In addition, the radiological impact on the public of such a hypothetical breach is nil. However, if the cask exterior should be visibly deformed in a severe accident, onlookers should be allowed no closer than about 500 yd and should be discouraged from loitering.

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# RADIOLOGICAL IMPACTS OF TRANSPORTING THREE MILE ISLAND CORE DEBRIS

## INTRODUCTION

Beginning in 1986, material from the damaged core of the Unit 2 reactor at the Three Mile Island Nuclear Power Station, near Harrisburg, PA, will be transported by rail to the Idaho National Engineering Laboratory (INEL), near Idaho Falls, ID. The core debris will be studied and tested in order to evaluate the course of events inside the reactor during the accident on March 28, 1979. The goal of the research is to improve engineering knowledge and understanding of that accident.

The core debris will be transported by rail in much the same way that spent reactor fuel is transported. It will be encased in a large cask made of stainless steel and other materials. The cask is designed and tested to survive practically all accidents. It also is designed to restrict the emanation of nuclear radiation to levels in accordance with Federal Regulation 10 CFR 71. There will be only one cask on a train. The train will be an ordinary freight hauler, operating under usual schedules, as determined by the railroad companies involved.

This document presents an assessment of the radiological impacts of one cask shipment. It focuses is on potential effects of the shipment on the public along the route. The document begins with a description of the shipping cask, followed by a description of the survivability tests required to confirm the cask design. Some actual accidents that similar casks have survived wholly intact are described. Next considered is the limit of radiation exposure dose rate that is imposed by regulatory agencies under normal conditions. No shipping of radioactive material is allowed unless the container is at or below the normal limit. A comparison is made between the normal radiation exposure limit and the radiation dose received annually by individuals from natural sources. Then, estimates of the radiation dose received by persons along the rail route in urban, suburban, and rural areas during normal transport are presented. Those times when the train stops for whatever reason (called rest stops) are considered also. Next, potential accident events are considered. Recent accident statistics are presented, and chances for an accident at different train velocities are estimated for any mile of track. Using that information and cask survivability test results, the possibilities for release of radioactive material are considered. All of the information is summarized in a table for easy reference. Only radiological impacts are considered because the trains operate the same way with or without a cask. The alternative of truck transport is considered briefly. In the last section of this document, the accident evacuation rate due to a hazardous materials spill is compared with the accident rate in urban and suburban areas with a cask aboard the train.

## CASK DESCRIPTION

The cask used for transporting core debris from Three Mile Island to INEL is similar to casks used for transporting spent nuclear fuel. There are thirteen types of casks licensed under the U.S. Code of Federal Regulations for transporting spent fuel by rail.[1] This section describes spent fuel casks in general, including the Three Mile Island cask.

A spent fuel cask is a massive, shielded steel container. The shielding is a material, such as lead, that limits the amount of radiation emitted to the outside of the container. There is a maximum radiation dose rate allowed, as discussed in the next section of this document. The outside surface temperature of the cask must not exceed 180°F, and the cask must survive a sequence of hypothetical accidents that confirm engineering performance criteria. Because of the structural strength, shielding, and heat removal requirements, the casks are massive, the largest ones weighing 100 tons or more.

A typical cask consists of a large, cylindrical metal outer vessel with a solid bottom and bolted lid with gasket. The cask is protected in case of an accident by external impact limiters that absorb shock energy. The closure area thus is protected by an energy-absorbing structure. Inside the cask is a layer of heavy metal such as lead or depleted uranium, limiting the emanation of radiation. Inside the heavy metal layer is another shell made of stainless steel. The spent fuel is contained inside the stainless steel layer. The factors that determine structural differences in transportation casks include the following: characteristics of the spent fuel, required internal capacity, and individual facility limitations, such as crane capacity and dimensional limitations.

Before being licensed, the effect of a sequence of hypothetical accident conditions on each cask type must be determined. That sequence, considered in the order applied, is as follows:

1. <u>Drop Test</u>--A 30-ft free-fall onto a flat, essentially unyielding, horizontal surface, striking the surface in a position for which maximum damage is expected.

2. <u>Puncture Test</u>--A 40-in. drop onto the upper end of a 6-in.-diameter, cylindrical, mild steel bar mounted vertically on an essentially unyielding, horizontal surface. The top of the bar must be horizontal, and its edge rounded to a radius of not more than 0.25 in.

3. <u>Thermal Test</u>--Exposure to a 30-min fire at 1475°F.

4. <u>Water-Immersion Test (Fissile Material)</u>--Submersion under a head of water of at least 3 ft, for not less than 8 h, and in the attitude for which maximum leakage is expected. This test is for fissile material in cases where water inleakage has not been assumed for criticality analysis.

5. <u>Water-Immersion Test (All Casks)</u>--Submersion under a head of water of at least 50 ft, for not less than 8 h.

After completion of the entire sequence of hypothetical accident conditions, it must be shown that the emitted radiation dose rate is less than 1000 mrem/h at a distance 3.3 ft from any point on the cask surface. [A rem is unit for dose to people by ionizing radiation corresponding to an amount of energy equal to 93 erg/g. A mrem is one-thousandth of that amount.] Under worst case assumptions, the dose rate at 6.6 ft from the cask might be as large as 500 mrem/h, given that the above limit is met exactly. This sequence represents engineering performance criteria. Casks must pass those criteria. Successful casks are rugged indeed, as may be seen by some crash tests now discussed.

A 15-ton cask was placed on a semi-trailer truck that subsequently was crashed into an immovable barrier at a speed of 28.5 mph.[2] The cask was fully instrumented in order to measure the forces on it and received a fraction of the stress it was designed to withstand. It remained tied in place on the trailer and was undamaged, while the tractor was completely demolished.

An additional series of tests was conducted in 1977 and 1978, involving crashing spent fuel casks mounted on railcars and tractor-trailer rigs.[3] Two trucks, each carrying a spent fuel cask, were crashed into a 690-ton concrete block, one at 60 mph and the other at 84 mph. At 60 mph the cask received superficial damage, while at 84 mph the cask was permanently deformed but within the limits predicted by computer calculations. In a third test, a cask on a semi-trailer was rammed from the side by a 120-ton locomotive moving at 81 mph. While the locomotive was demolished, the cask suffered minor damage, again as predicted. In a fourth test, a cask on a railcar was crashed into the 690-ton concrete block. Again the cask behaved as predicted.

In a final test in this series, a railcar-mounted cask was immersed in a 30 x 60-ft, concrete-lined pool containing jet aviation fuel that was ignited. Approximately 65,000 gal of fuel were burned in a 2-h period. The cask became very hot, but the behavior of the cask remained within predicted limits.

In none of the five tests outlined above would there have been any significant release of radioactive material to the atmosphere as a result of the event, had the cask been carrying spent fuel. The tests confirmed that the hypothetical accident sequence provided sufficiently severe engineering performance criteria for licensing the cask design. The tests also confirmed the validity of the computer calculations for predicting cask behavior under severe accident conditions.

Other tests have been conducted to compare damage resulting from a cask impacting typical surfaces with damage resulting from a cask impacting an unyielding surface in the 30-ft drop test. In 1975, an 8-ton cask was dropped 30 ft onto an unyielding target.[4] The cask did not fail in any way, but it did suffer visible deformation on the outer surface. Then an identical cask was dropped 2000 ft onto hardpan desert soil. The cask struck the earth at a velocity of 235 mph and penetrated about 52 in. into the soil. The resulting damage to the cask consisted entirely of paint scratches.

In tests reported in 1980, the relationship between target hardness and package damage was investigated again.[5] A series of steel bodies were dropped from various heights onto three different targets. The following targets were used: compacted soil, 2 ft of reinforced concrete, and an unyielding target. Data obtained from the tests showed that a 30-mph impact onto an unyielding target is equivalent to an impact at about 90 mph onto 2 ft of reinforced concrete, and about 120 mph onto 1 ft of reinforced concrete. Those tests confirm that realistic targets absorb crash energy as they deform, so there is less energy, relative to an unyielding target, for damaging a cask.

Actual accident experience also confirms the test results. In the 12-yr period from 1971 through 1982, spent fuel casks and similar casks were involved in five moving transportation accidents, one on a railroad (derailment) and four on highways (Reference 1). [This includes Department of Energy experience.] None of the casks suffered a failure. During that period, there were 104 accidents involving Type B packages, of which spent fuel casks are one kind. The effects from the series of hypothetical accident conditions described earlier must be determined for all Type B packages. In the 104 accidents, there were no package failures and, consequently, no radioactive releases occurred.

## STATUTORY LIMITS ON EMITTED RADIATION

The U.S. Department of Transportation and the U.S. Nuclear Regulatory Commission have issued regulations limiting the maximum radiation dose rate from a shipment of radioactive material. In the case of a spent fuel cask on a railroad flatcar, the maximum allowable dose rate is 10 mrem/h at a point 6.6 feet from the outer edge of the car (Reference 1). In practice, the dose rate is kept much below that limit. However, the maximum allowable rate may be put into perspective by comparing it to the annual dose each person receives from natural radiation (i.e., 100 to 130 mrem/yr).[6] Natural radiation comes from such things as cosmic rays, granite, and other naturally occurring radioactive materials. Natural radiation does not include medical applications, nuclear bomb fallout, industrial applications, or nuclear power generation. Medical applications (x-rays, etc.) add about 86 mrem/yr, on the average. At the 10-mrem/h limit for transport, a person would have to loiter 7 ft from a cask on a rail flatcar for about 10 h to receive the naturally occurring dose. Such action by itself would be risky, since 465 trespassers around railroads were killed in 1983 (excluding train accidents).[7] Likewise, the trespassers would have to loiter for about 8 to 9 h in order to accumulate the average medical dose.

It is important to realize that the dose rate diminishes rapidly with distance from the cask. For example, the maximum rate at 22 yd is 1 mrem/h or less. Most people will be at greater distances than that and exposed much less than an hour.

In this report, radiological impacts for normal transport are computed based on the maximum allowable dose rate.

# RADIOLOGICAL IMPACTS OF INCIDENT-FREE TRANSPORT

In this section, estimates of the radiation dose received by all people residing near the railroad upon which a spent fuel cask travels are discussed. Estimates are made for a typical mile of railroad track. This kind of estimate is called a "Unit Consequence Factor" and is abbreviated with the initials UCF. The UCF is a convenience, since the total cumulative dose for a region can be calculated by simply multiplying it by the mileage.

The UCF is estimated for each of the following representative areas: urban, suburban, and rural. Each area is assigned a uniform population density; that is, number of people per square mile. In the estimates presented later, the population densities are as follows: urban, 10,000; suburban, 1860; and rural, 16. The areas used for estimating the number of exposed people extend one-half mile on each side of the track. It is assumed there are no residents within a certain distance from the track in each area. The inside limits are: urban, 16 ft; suburban, 86 ft; and rural, 86 ft. It should be noted that the dose rate at one-half mile is less than one-millionth that at 98 feet.[8] The total (cumulative) dose to people as the train passes by at representative speeds is calculated. The speeds are: urban, 15 mph; suburban, 25 mph; and rural, 40 mph. Calculated estimates of typical radiation exposures in each area are presented. They all are derived from the computed results presented in Reference 9.

## Urban Areas

In urban areas, the UCF is estimated to be $7 \times 10^{-5}$ person-rem per mile of track. In other words, it would take 14,300 miles of urban track to accumulate one person-rem among all people residing within one-half mile of the track. In one mile of track, the number of such people is 9940. On the average, one person receives $7 \times 10^{-6}$ mrem from each cask. This may be compared with the Federal Radiation Council guideline that says no member of the general public should receive more than 500 mrem/yr above that from natural radiation and medical exposure.[10] In other words, it would take the passage of about 71 million spent fuel casks in one year for the dose to one person, on the average, to reach the guideline limit. Looking at this another way and recalling that everyone receives about 100 mrem/yr from natural causes, it would take the passage of about 14 million spent fuel casks in one year for one person, on the average, to match the annual natural radiation dose.

## Suburban Areas

In suburban areas, the UCF is estimated to be $7 \times 10^{-6}$ person-rem per mile of track. In other words, it would take about 143,000 miles of suburban track to accumulate one person-rem among all people residing within one-half mile of the track. In one mile of track, the number of such people is 1800. On the average, one person receives about $4 \times 10^{-6}$ mrem from each cask. Again, this is far less than the Federal Radiation Council guideline of 500 mrem/yr. It would take the passage of 125 million spent fuel casks in one year to match the guideline, on the average. In order to match the natural radiation dose, it would take the passage of 25 million spent fuel casks in one year.

## Rural Areas

In rural areas, the UCF is estimated to be $4 \times 10^{-8}$ person-rem per mile of track. It would take about 25 million miles of rural track to accumulate one person-rem among all people residing within one-half mile of the track. In one mile of track, the number of such people, on the average, is 15.5. Thus, the average person receives about $3 \times 10^{-6}$ mrem from each cask. Again, this is far less than the Federal Radiation Council guideline of 500 mrem/yr and also the annual natural radiation dose of 100 mrem. It would take the passage of 190 million and 38 million spent fuel casks, respectively, in one year to equal these doses.

## Rest Stops

Trains stop occasionally for such reasons as changing the crew and waiting for track clearance. The UCF for such stops is estimated to be $3 \times 10^{-3}$ person-rem/h. To obtain this estimate, it was assumed that 100 persons gather around the cask, at a distance 22 yd from it, for a period of 1 h. If people were to behave in this manner, each person would receive a dose of 0.03 mrem every hour. In order to match the Federal Radiation Council guideline or the annual natural radiation dose, a person would have to loiter near a cask for 16,700 h/yr or 3300 h/yr, respectively. The first instance is impossible, since there are only 8760 h in a year; and the second represents a waste of almost 40% of a year.

## Individual Exposed to the Maximum Extent

The maximum dose is hereby defined to be that received by an individual in an urban area who is standing about 33 ft from the edge of the railcar as it passes by. The train is assumed to be moving at 15 mph. The spent fuel cask is about 23-ft long. A procedure for calculating the dose can be found in Reference 11, and the value is $2 \times 10^{-3}$ mrem. It would take the passage of about 242,000 spent fuel casks in one year (about 28 every hour) for the maximum individual dose to match the Federal Radiation Council guideline. Similarly, it would take about 48,000 casks passing by to match the annual natural radiation dose.

## RADIOLOGICAL IMPACTS UNDER ACCIDENT CONDITIONS

Railway accidents do occur. It is conceivable that such an accident could dislodge a spent fuel cask from a flatcar. But, the sequence of hypothetical accident conditions discussed earlier shows that the chance of the cask falling, and thereby releasing radioactive material, is remote. Nevertheless, railroad accident statistics for 1983 are examined to assess the possibility of a "stalled train." It should be evident from the previous discussion under the section entitled "Rest Stops," that a local Emergency Response Team should keep onlookers moving along and as far away from a stalled train carrying a spent fuel cask as reasonably practical.

### Accident Statistics

Reference 7 contains 1983 statistics on accidents resulting in more than $4500 damage. Table 10 in that reference (p. 18) lists the number of accidents on mainline track verses speed, and that table is reproduced partially here as Table 1. The table shows that total of 1867 accidents occurred on mainline track. Other accidents occurred that year in railroad yards and on sidings, for an overall total of 3906. Thus, about 48% of all accidents happened on mainline track. If the "locomotive train miles" are considered as appropriate for mainline track mileage (408 million miles), the accident rate is found to be about 4.6 per million miles. Now consider the speed distribution. From Table 1, at least 1360 mainline track accidents occurred at speeds less than 31 mph; that is, 74% of those with reported speed (1834). The cask testing sequence shows that no cask could be breached at those velocities even if it struck an unyielding barrier. Thus, an accident at those speeds, which are representative of speeds in urban and suburban areas, cause what was referred to above as a "stalled train." The accident rate is estimated as 74% of the overall accident rate for mainline track, or about 3.4 accidents per million miles. In other words, one train in 294,000 (on the average) will stall on a particular mile of mainline track in urban and suburban areas because of an accident.

TABLE 1. RAIL ACCIDENTS ON MAINLINE TRACK VERUS SPEED FOR 1983[a]

| Speed (mph) | Total Accidents | Collisions | Derailments | Other |
|---|---|---|---|---|
| Unknown | 33 | 2 | 16 | 15 |
| 1-10 | 643 | 45 | 557 | 41 |
| 11-20 | 349 | 17 | 299 | 33 |
| 21-30 | 368 | 18 | 299 | 51 |
| 31-40 | 241 | 10 | 181 | 50 |
| 41-50 | 144 | 2 | 91 | 51 |
| 51-60 | 55 | -- | 34 | 21 |
| 61-70 | 24 | 3 | 8 | 13 |
| 71-80 | 6 | -- | 1 | 5 |
| 81-90 | 3 | -- | -- | 3 |
| ≧91 | 1 | -- | -- | 1 |
| Total | 1867 | 97 | 1486 | 284 |

a. Reference 7.

In 1983, 26% of the railroad accidents on mainline track occurred at speeds greater than 30 mph (Reference 7). Most of those, if not all, must have occurred in rural areas, because of the speed limits in communities. The accident rate on mainline track in rural areas is then about 1.2 accidents per million miles. In other words, one train in about 830,000 (on the average) will stall on a particular mile if mainline track in a rural area because of an accident. The cask testing sequence shows that it would take a severe accident at a speed over 90 mph to cause a breach of a spent fuel cask. In 1983, one train accident occurred at a speed over 91 mph (Reference 7). It resulted from equipment failure, and there was no track damage. However, that accident would not have caused any damage to a cask, had there been one on board. An accident in a rural area with a spent fuel cask on board thus represents a stalled train case, where the Emergency Response Team needs only keep onlookers from getting close to the cask.

If a cask is involved in a severe accident, as for example a derailment, and also suffers visible exterior deformation as a result, the dose rate in the immediate vicinity in the worst case might be as much as 50 times greater than the incident-free dose rate (500 mrem/h versus 10 mrem/h at 6.6-ft away). In that event, it would be prudent to allow onlookers no closer than about 500 yd and keep them moving along. At a distance of 500 yd, the dose rate would be no greater than about 0.01 mrem/h.

In the unlikely event that a cask from Three Mile Island is breached in a rail accident in a rural area, no significant side effects would result. Much of the core debris is known to be hard, ceramic-like material. Such material can be carried only a short distance by wind, if at all. The core material has cooled for about seven years; therefore, it is much less radioactive than spent fuel that has cooled for 150 days. [No spent fuel may be shipped from a power plant until it has cooled for at least 150 days.] Experiments designed to force material from a spent fuel cask through an unrealistically large opening have been conducted (Reference 11). In those experiments, the amount of material that could be forced out was small. Thus, if the material released was spent fuel cooled for 150 days, even in ultradensely populated New York City under the worst possible meteorological conditions, no immediate fatality would result and one delayed cancer fatality might result. Therefore, a potential breach of a Three Mile Island cask in a rural area is no threat to public health and safety. To be sure, the material would have to be cleaned up; but such cleanup is well within present capabilities.

## SUMMARY OF RADIOLOGICAL IMPACTS

The radiological impacts of transporting the core debris from the damaged reactor at Three Mile Island to INEL are summarized in Table 2. The impacts for incident-free transport (except for rest stops) are presented in terms of the number of casks required to match a guideline adopted by the Federal Radiation Council and now adopted by the Environmental Protection Agency.[12] In the case of rest stops, the impact is presented in terms of the time an individual would have to loiter near a cask (16,700 h) to match the annual guideline. It should be noted that there are insufficient hours in a year to do this.

For accident conditions, there are no expected releases of radioactive material (RAM), because the shipping casks are so rugged. Accident rates in three areas (urban, suburban, and rural) are estimated. Because no RAM is released, the radiological impacts of those events would be similar to those for rest stops when the cask exterior is underformed. If the cask exterior should be visibly deformed in a severe accident, onlookers should be allowed no closer than about 500 yd and loitering should be discouraged.

TABLE 2. SUMMARY OF RADIOLOGICAL IMPACTS OF TRANSPORTING CORE DEBRIS FROM THREE MILE ISLAND TO INEL

| | Incident-Free Transport | Accident Conditions | |
|---|---|---|---|
| Area | Conditions to Match Federal Radiation Council Annual Guideline | Accident Rate, one train in | Result |
| Urban | 71,000,000 casks (8100 per hour) | 294,000 | No RAM release. |
| Suburban | 125,000,000 casks (14,000 per hour) | 294,000 | No RAM release. |
| Rural | 190,000,000 casks (22,000 per hour) | 830,000 | Extremely unlikely to release RAM; no health effect; restricted loitering. |
| Maximum Individual | 242,000 casks (28 per hour) | | |
| Rest Stop | Loitering for 16,700 hours | | |

RAM = radioactive material.

## ALTERNATIVE HIGHWAY TRANSPORT

A cask could be transported over highways by truck. Accident rates are nearly the same for trucks as for railroads (Reference 10). However, there are two factors favoring rail transport. One is that the mileage generally is greater for trucks, especially if the trucks are routed through less densely populated areas. The radiological impact of transporting RAM is directly proportional to mileage and inversely proportional to population density; the nonradiological impact of transporting RAM is directly proportional to mileage. Therefore, the net effect is that truck and rail transport result in about the same radiological impacts, but trucks result in greater nonradiological impacts. The second factor is that trucks must carry smaller casks because of highway weight limitations. Consequently, more truck trips would be required than rail trips. The effect would be greater risk of a highway accident and larger transportation cost as well.

## COMPARISON WITH OTHER HAZARDOUS MATERIALS

Railroads transport other hazardous materials, such as chlorine, liquefied petroleum gas, vinyl chloride, industrial acid, and other chemicals. People live with, and accept the risks of, transportation of those materials. A comparison is made of accident rates involving hazardous materials with those involving a cask with core debris from Three Mile Island.

In 1983, hazardous materials were involved in 431 railroad accidents (Reference 7, p. 37). In those accidents, hazardous material was released from 62 cars, causing the evacuation of 3500 people. The type of track (mainline, yard, or siding) is not listed; so, in order to estimate an accident evacuation rate, use is made of the total mileage for the year (558.191 million miles). The accident evacuation rate was calculated to be about 6.3 people per million miles. The mainline track accident rate in urban and suburban areas (3.4 accidents per million miles) is compared with the evacuation rate. A stalled train carrying a spent fuel cask in those areas would necessitate evacuating very few people, if any; therefore, it is reasonable to compare the two rates. Since $(6.3 \div 3.4) = 1.85$, it is 85% more likely that a person would be evacuated because of a hazardous material accident than because of a stalled train carrying a spent fuel cask (based on 1983 data).

## REFERENCES


1. T. A. Wolff, The Transportation of Nuclear Materials, SAND84-0062, December 1984, pp. 24, 29.

2. Kelly and Stoddart, Highway Vehicle Impact Studies: Tests, Methodical Analysis of Vehicle, Package, and Tie Down Systems, ORNL-NSIC-61, February 1970, pp. 4, 7, 48, 55. Cited in Directorate of Regulatory Standards, U.S. Atomic Energy Commission, Environmental Survey of Transportation of Radioactive Materials to and from Nuclear Power Plants, WASH-1238, December 1972, p. 73.

3. H. R. Yoshimura and M. Huerta, Scale Modeling, and Full-Scale Testing of, Shipping Containers for Radioactive Materials, U.S. Department of Commerce/National Bureau of Standards, NBS Special Publication 652, Proceedings of the 34the Meeting of the Mechanical Failure Prevention Group, p. 261. Cited by R. M. Jefferson, Consideration of the Safety of Transporting Spent Fuel, SAND84-2128, January 1985, pp. 11-13.

4. I. G. Waddoups, Air Drop Test of Shielded Radioactive Material Containers, SAD75-0276, September 1975.

5. J. D. McClure, et al., "Relative Response of Type B Packagings to Regulatory and Other Impact Test Environments," Proceedings of the International Symposium on Packaging and Transportation of Radioactive Materials, Berlin, November 1980 (PATRAM '80).

6. D. C. Stewart, Handling Radioactivity, New York: John Wiley and Sons, 1981, pp. 7, 14, 25.

7. U.S. Department of Transportation, Accident/Incident Bulletin, Federal Railroad Administration No. 152, June 1984, pp. 3, 18, 23, 37, 55.

8. J. M. Taylor and S. L. Daniel, RADTRAN II: Revised Computer Code to Analyze Transportation of Radioactive Material, SAND80-1943, October 1982, p. 10.

9. N. C. Finley, et al., The Transportation of Radioactive Material (RAM) to and from U.S. Nuclear Power Plants, NUREG/CR-2325, SAND81-0118, December 1983, p. A-24.

10. U.S. Atomic Energy Commission, Environmental Survey of Transportation of Radioactive Materials to and from Nuclear Power Plants, WASH-1238, December 1972, p. 1.

11. E. L. Wilmot, et al., A Preliminary Analysis of the Cost and Risk of Transporting Nuclear Waste to Potential Candidate Commercial Repository Sites, SAND83-0867, June 1983, pp. 31, 43.

12. J. E. Till and H. R. Meyer (eds.), Radiological Assessment, NUREG/CR-3332, ORNL-5968, September 1983, p. 12-7.